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Stand-Yield Prediction for Managed Ocala Sand Pine

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Abstract

Sand pine is a very important species in Florida, producing significant quantities of fiber. The purpose of this study was to develop the site index and stand-level growth and yield equations managers need to make informed decisions. Data were collected from 35 seeded plots of Ocala sand pine covering a range of site indexes, ages, and densities in 1982-83. These plots were remeasured 5 and 10 years later and the data used to develop growth and yield equations by tree component. Equations for both current and future yields in volume and weight measures are given. These equations gave very good results when tested by comparing actual yields with predicted yields for a second set of 22 sand pine plantations measured in the panhandle area of Florida.

Keywords: Biomass, growth, site index, survival, yield.

Introduction

Sites with deep, sandy soils form a small but significant land resource [3.2 million hectares (ha)] in the Southeastern United States. The Choctawhatchee (*Pinus clausa* var. *immuginata* D.B. Ward) and Ocala (*P. clausa* var. *clausa*) varieties of sand pine grow naturally on these dry, sandy sites in northwestern and peninsular Florida, respectively. Many of the sandy sites in Florida, once occupied by low-quality scrub oaks generally unsuitable for forest products, have been converted to sand pine. Sand pine has also been extensively planted on sandy sites in Georgia and South Carolina (Burns 1973, Hebb 1981, McNab and Carter 1981, Preston and Price 1979).

Producers and managers are interested in expected growth and yield for these sand pine stands. Prediction equations for individual tree contents have been developed (McNab and others 1985, Rockwood and others 1987, Taras 1980), but equations for site index (SI) and stand-level yields from Ocala sand pine are not available. This paper presents equations developed to quantify SI, tree mortality, aboveground biomass, and growth and yield for Ocala sand pine stands in Florida.

Materials and Methods

Study Area

Ocala sand pine stands were randomly selected to represent a range of stand densities and ages (table 1). Most of the stands were less than 20 years old because few stands in the older age classes (20 to 40 years) could be located. The 35 stands in Marion County, located in the center of Florida on the Ocala National Forest, had originated from direct seeding after clearcutting or from natural regeneration. Planting had established the stands located in nearby Putnam and St. Johns Counties. Planted stands located in the panhandle area of west Florida made up the remainder of the sample.

Sand pine stands in the Ocala National Forest and those nearby in Putnam and St. Johns Counties were growing on Astatula or Paola sand soils (hyperthermic, uncoated Quartzipsamments). These soils consist of deep, droughty sand deposits from former dunes, offshore bars, and barrier

Table 1—Distribution of 57 Ocala sand pine biomass plots by initial age and location in Florida

Location (county)	Age (years) 5-10	11-15	16-20	21-25	36-40	Total
	Number of plots					
Bay	--	--	2	--	--	2
Gilchrist	--	1	--	--	--	1
Marion	14	12	4	4	1	35
Okaloosa	1	1	3	--	--	5
Putnam	2	--	--	--	--	2
St. Johns	--	--	3	--	--	3
Taylor	--	--	--	1	--	1
Walton	--	2	2	--	--	4
Washington	--	1	3	--	--	4
Total	17	17	17	5	1	57

islands. The complex, undulating topography generally has slopes from 0 to 8 percent with occasionally steeper areas near sinks and lakes. Planted stands in the panhandle area were on Lakeland sand (thermic coated typic Quartzipsamment). Lakeland soil formed from sand deposited by oceans, rivers, and wind. The terrain is broad, nearly level to gently sloping with gradients from 0 to 12 percent.

Inventory

Between June 1982 and December 1983, 57 permanent plots were installed in the study area—one plot per stand (table 1). Square 15- by 15-meter (m) plots were installed in low density stands (<2,000 trees per ha). Smaller 10- by 10-m plots were installed in high density stands ($\geq$2,000 trees per ha). All trees on these plots were tagged and numbered, and diameter at breast height (d.b.h.) was measured to the nearest millimeter (mm). Total height and height to the base of the live crown were measured to the nearest 0.5 m for all trees. Trees on the 35 plots located on the Ocala National Forest were remeasured 5 (1987-88) and 10 (1992-93) years after initial plot establishment.

Data Summary and Analysis

Using equations developed by Rockwood and others (1987), 20 biomass components were estimated for every tree on each sample plot: stem wood volume inside bark (SVIB), stem volume outside bark (SVOB), and green and dry weight for stem wood, stem bark, stem, branch wood, branch bark, branch, foliage, crown, and tree (table 2). Summing values for all trees on a plot provided yields on a per area basis.

Site index function and curves—Polymorphic SI curves were developed using the initial height and age of up to 10 dominant and codominant trees on each of the 35 Ocala National Forest plots. Our height-age model was based on a modified form of the equation used by Bailey and Clutter (1974) and Cao and Durand (1991):

$$H = \exp\left[a + b * (1 / A)^c\right] , \qquad \textbf{(1)}$$

where

H = average height in m of the dominant and codominant trees,
A = stand age in years, and
a, b, and c = coefficients estimated from the data.

Applying the natural logarithm to equation (1) produced the following equation:

$$1n\ (H) = a + b * (1 / A)^c , \qquad \textbf{(2)}$$

where

$1n\ (H)$ = the natural logarithm of H.

Assuming b from the above equation (2) varies with different plots, b was expressed in terms of SI and base age (SA):

$b = [\ln (\text{SI}) - \text{a}] * (\text{SA})^c$.

Replacing b in equation (2) resulted in the polymorphic SI model:

$$1n\ (H) = a + [1n\ (SI) - a] * (SA / A)^c . \qquad \textbf{(3)}$$

Survival prediction—A fairly broad spectrum of tree survival data were gathered from the Ocala National Forest plots over the 10-year period of the study. Initial tree ages ranged from 5 to 40 years, and initial densities from 444 to 22,000 trees per ha. The survival model of Clutter and Jones (1980) and Pienaar and others (1990) was applied to these data:

$$\begin{aligned} N2 = N1 * \{&\exp [a + 1n\ (A2 / 10)^b \\ &+ 1n\ (N1)^c] / \exp [a \\ &+ 1n\ (A1 / 10)^b + 1n\ (N1)^c]\} , \end{aligned} \qquad \textbf{(4)}$$

where

$A1$ = initial stand age in years,
$N1$ = the initial number of trees per ha,
$A2$ = future stand age in years,
$N2$ = surviving trees per ha at age $A2$, and
a, b, and c = coefficients estimated from the data.

Table 2—Coefficients for predicting current and future Ocala sand pine stand contents for 20 components[a]

Component	Equation parameters						
	a1	a2	a3	a4	a5	R^2	b
Stem wood							
Vol. I.B.	14.5109	-0.2159	0.3858	1.3508	-4.5843	0.9886	941.1
Green wt.	14.4191	- .2154	.3865	1.3428	-4.5938	.9842	1314.2
Dry wt.	13.6502	- .2156	.3863	1.3450	-4.5903	.9841	548.2
Stem bark							
Green wt.	12.2919	- .2115	.3914	1.3290	-4.6798	.9839	627.6
Dry wt.	11.7061	- .2118	.3910	1.3304	-4.6743	.9840	327.8
Stem							
Vol. O.B.	14.5251	- .2061	.3941	1.3236	-4.5986	.9871	1728.4
Green wt.	14.5317	- .2150	.3871	1.3462	-4.6081	.9843	1941.4
Dry wt.	13.7838	- .2151	.3870	1.3465	-4.6051	.9839	875.9
Branch wood							
Green wt.	13.4589	- .2122	.3906	1.3322	-4.6672	.9837	1739.3
Dry wt.	12.6711	- .2126	.3901	1.3345	-4.6581	.9839	706.2
Branch bark							
Green wt.	12.7434	- .2103	.3929	1.3226	-4.7021	.9833	700.4
Dry wt.	11.0706	- .2084	.3950	1.3132	-4.7323	.9820	319.5
Branch							
Green wt.	13.6998	- .2118	.3911	1.3301	-4.6754	.9840	2437.6
Dry wt.	12.8516	- .2119	.3911	1.3305	-4.6739	.9836	1025.6
Foliage							
Green wt.	12.6991	- .2033	.4004	1.2878	-4.7840	.9764	2506.5
Dry wt.	11.7446	- .2031	.4002	1.2867	-4.7853	.9762	982.0
Crown							
Green wt.	13.9931	- .2094	.3938	1.3184	-4.7164	.9828	4945.1
Dry wt.	13.1179	- .2096	.3936	1.3194	-4.7133	.9829	2007.5
Tree							
Green wt.	14.9283	- .2128	.3899	1.3352	-4.6556	.9839	6887.4
Dry wt.	14.1305	- .2131	.3895	1.3366	-4.6493	.9840	2883.5

Vol. I.B. = volume inside bark; Vol. O.B. = volume outside bark.

[a] $Y = a + \ln \{b * N + c * \exp [a1 + \ln (N)^{a2} + \ln (SI)^{a3} + \ln (B)^{a4} + a5 * \ln (1 / A)]\}$ with B in m^2, n in trees per hectare, a = -13.8155 and c = 1.

Basal area prediction—Basal area (B in m^2 per ha) calculations were based on live tree data. A basal area prediction model was developed using *SI*, density *(N)*, and age *(A)* as independent variables:

$$B = \exp\left[a + 1n\,(SI)^b + 1n\,(N)^c + d * (1 / A) + 1n\,(N * 1 / A)^f\right], \quad \textbf{(5)}$$

where

a, *b*, *c*, *d*, and *f* = coefficients estimated from the data.

Stand-level growth and yield equations—Equations, based on the data collected from the Ocala National Forest plots at time 0, 5, and 10 years, were developed to predict yield. Using age, surviving trees per ha, *SI*, and basal area, the following equations were generated:

$$1n\ (Y) = a + 1n\,\{b * N + c * \exp\left[F\ (N, SI, B, A)\right]\}, \quad \textbf{(6)}$$

where

Y = the stand yield per ha, and
a, *b*, and *c* = coefficients estimated from the data.

$$F\ (N, SI, B, A) = a1 + \ln\,(N)^{a2} + \ln\,(SI)^{a3} + \ln\,(B)^{a4} + a5 * (1 / A),$$

where

*a*1, *a*2, *a*3, *a*4, and *a*5 = coefficients estimated from the data.

Model evaluation and verification—To test against an independent data set, the models developed from the 35 Ocala National Forest plots were tested against the values measured in 1982 and 1983 on the 22 plots in the planted stands. To test actual and predicted data, they were compared using the following equation:

$$P\ (V) = a + b * A\ (V), \quad \textbf{(7)}$$

where

P (V) = the predicted volume, and
A (V) = the actual volume.

Results and Discussion

Site index—Data from the 35 sites on the Ocala National Forest provided the following solutions to equation (3):

$$1n\ (H) = 6.435 + \left[1n\ (SI) - 6.435\right] * (50 / A)^{0.5315}. \quad \textbf{(8)}$$

Site index in m for Ocala sand pine at SA 50 years was determined by solving equation (8) for *SI*:

$$SI = \exp\,\{6.435 + \left[1n\ (H) - 6.435\right] * (A / 50)^{0.5315}\} / 10. \quad \textbf{(9)}$$

Site index estimates for each plot and SI curves were constructed from equation (9).

The seeded and planted plots represented a range of site indices (fig. 1). Within the 35 seeded stands, the youngest plots were on sites with indices ranging widely from 14 to 32 m. Plots in lower density stands initially 16 to 25 years of age had SIs from 20 to 30 m. A trend toward decreasing SI with increasing age suggests a possible bias in the data; the oldest seeded stand was located on a poor site.

Plots in planted stands represented a somewhat similar range of site conditions. Plantations from 11 to 25 years of age were on sites predicted to grow trees 20 to 30 m tall in 50 years. Plots in the youngest plantations had high SIs.

The SI curves presented in figure 2 show the polymorphic height growth expected over a 50-year period. Height growth on good sites is predicted to be rapid at early ages, with decreasing rates at older ages. On poorer sites, height growth is expected to be less but more consistent over time.

Survival prediction—The survival equation generated from equation (4) for initial densities of less than 18,200 trees per ha follows:

$$N2 = N1 * \exp\left[1.6817 + 1n\ (A2 / 10)^{-0.5005} + 1n\ (N1)^{0.7954}\right] / \{\exp\left[1.6817 + 1n\ (A1 / 10)^{-0.5005} + 1n\ (N1)^{0.7954}\right]\}, \quad \textbf{(10)}$$

with $R^2 = 0.946$.

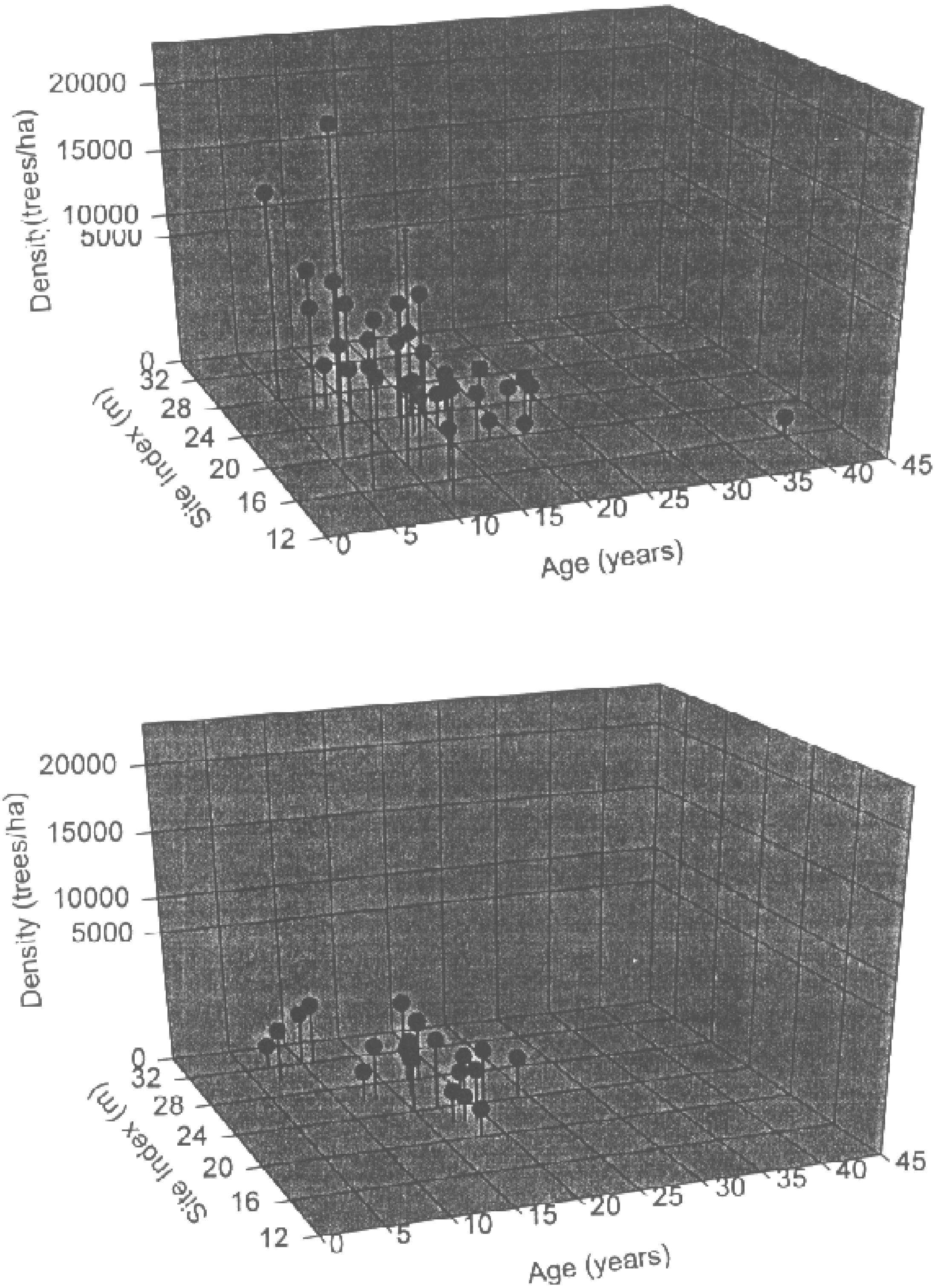
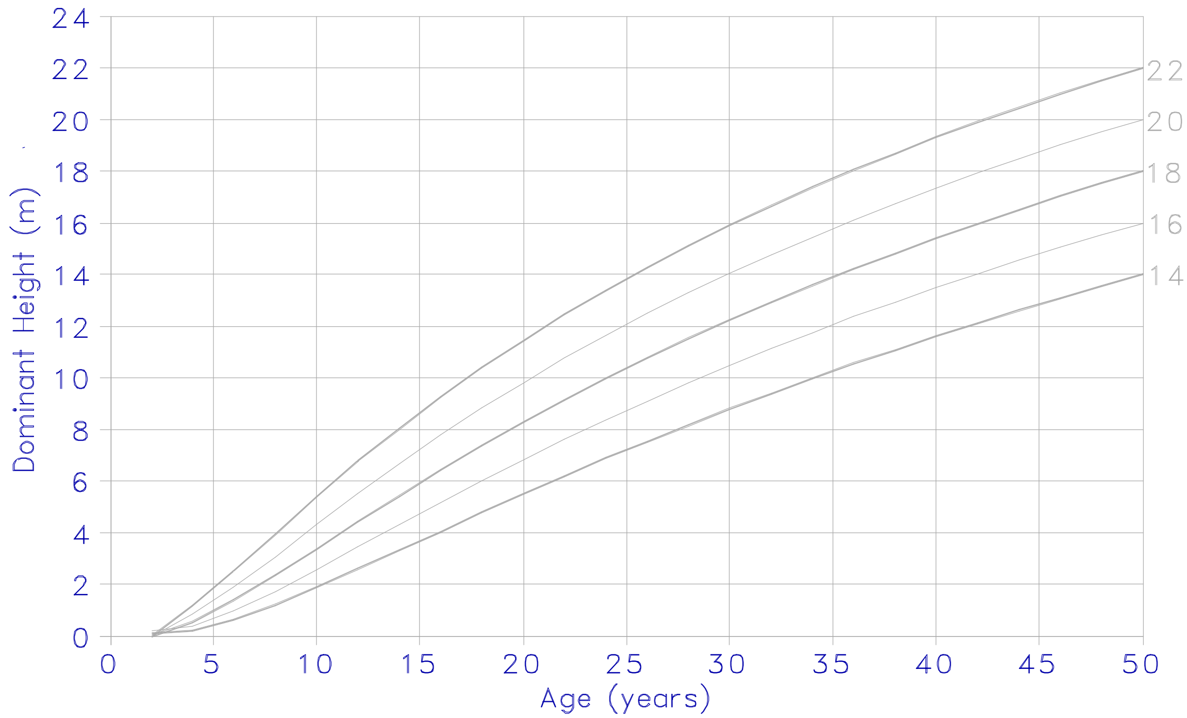


Figure 1—Distribution of seeded (top) and planted (bottom) Ocala sand pine plots by initial age, density, and site index.



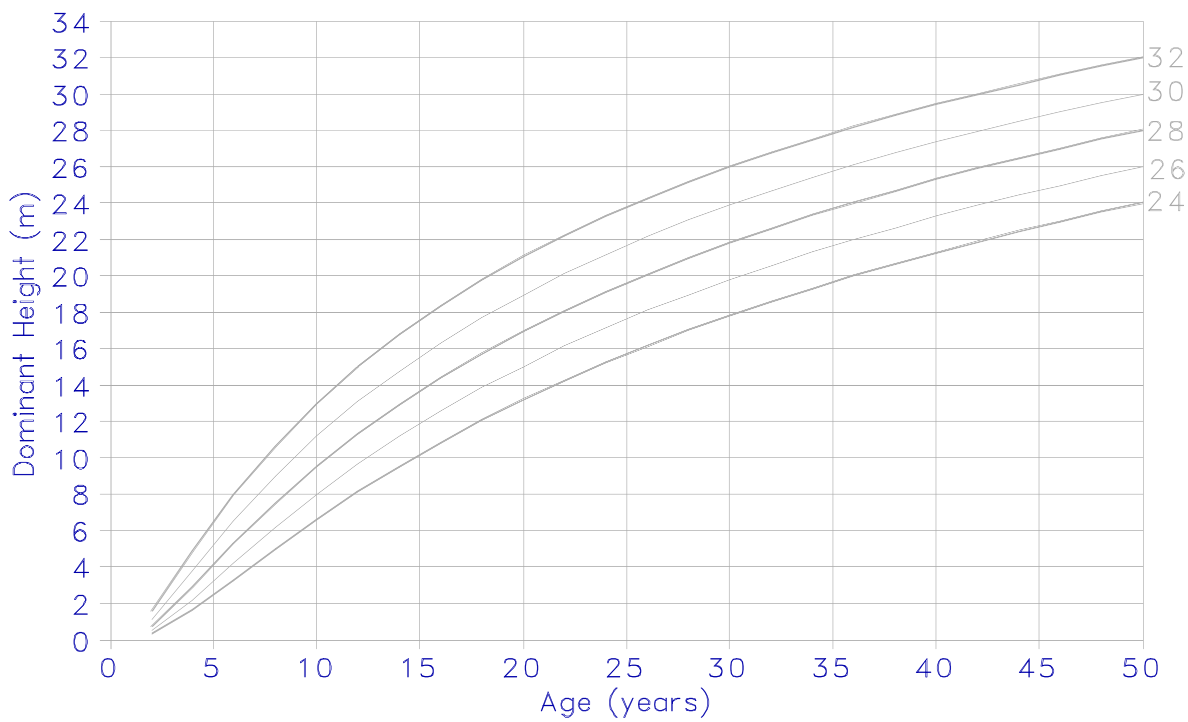


Figure 2—Base-age 50 years site index curves for Ocala sand pine: site indices 14, 16, 18, 20, and 22 (top); site indices 24, 26, 28, 30, and 32 (bottom).

The high R^2 is important because survival prediction is critical to accurate growth and yield prediction.

Figure 3 shows survival curves for six initial densities ranging from 1,100 to 18,000 trees per ha from ages 6 to 50. Survival is predicted to drop significantly for initial densities ≥12,000 such that by age 50 stand densities are near 4,000 trees per ha.

Basal area prediction—A simultaneous estimation procedure following techniques of Pienaar and others (1990) was used to estimate parameters in equations (11) and (12). Applying model (5), current sand pine basal area in m^2 per ha can be predicted:

$$\begin{aligned} B1 = \exp[&-0.030 + 1n\,(SI)^{1.3915} \\ &+ 1n\,(N)^{0.7487} - 16.9491 \\ &* (1 / A) - 1n\,(N1 \\ &* 1 / A)^{0.3357}] / 100\ , \end{aligned} \tag{11}$$

with R^2 = 0.8263, and future basal area (B2) can be projected:

$$\begin{aligned} B2 = B1 * \exp[&-0.030 + 1n\,(SI)^{1.3915} \\ &+ 1n\,(N2)^{0.7487} - 16.9491 \\ &* (1 / A2) - 1n\,(N2 * 1 / A2)^{0.3357}] \\ &/ \exp[-0.030 + 1n\,(SI)^{1.3915} \\ &+ 1n\,(N1)^{0.7487} - 16.9491 * (1 / A1) \\ &- 1n\,(N1 * 1 / A1)^{0.3357}]\ . \end{aligned} \tag{12}$$

These two equations are compatible because the projection equation uses the same coefficients in a different form of the prediction equation. This ensures that the basal area projected at age *A*2 from the basal area at age *A*1 with equation (12) will be the same as the predicted basal area at age *A*2 given by equation (11) with *N*2 and *SI*. Figure 4 shows stand basal areas for six initial densities and four SIs.

Stand-level growth and yield equations—Stand average tree contents (Rockwood and others 1987) were successfully modeled as functions of stand basal area, SI, and age. For example, a stand's average tree SVOB (m^3) can be calculated:

$$\begin{aligned} 1n\,(SVOB) = -13.8155 + 1n\,\{&1.728 * 10^3 \\ &+ \exp[2.7610 + 1n\,(B)^{1.28766} \\ &+ 1n\,(SI)^{0.4381} - 5.3366 \\ &* (1 / A) + 1n\,(N)^{0.06528}]\}\ , \end{aligned} \tag{13}$$

with R^2 = 0.986
n = 3525.

Stand SVOB (SSVOB in m^3 per ha) (table 2) can then be calculated:

$$\begin{aligned} 1n\,(SSVOB) = -13.8155 + 1n\,\{&1.728 \\ &* 10^3 * N + \exp[14.5251 \\ &- 1n\,(N)^{0.206} + 1n\,(SI)^{0.394} \\ &+ 1n\,(B)^{1.323} - 4.5986 \\ &* (1 / A)]\}\ , \end{aligned} \tag{14}$$

with R^2 = 0.987.

Using equation (14) in a simultaneous estimation procedure, the future SSVOB projection model was developed:

$$\begin{aligned} SSVOB2 = SSVOB1 * (\{&1.728 * 10^3 * N2 \\ &+ \exp[14.5251 - 1n\,(N2)^{0.206} \\ &+ 1n\,(SI)^{0.394} + 1n\,(B2)^{1.323} \\ &- 4.5996 * (1 / A2)]\} / 1.728 \\ &* 10^3 * N1 + \exp[8.4808 \\ &- 1n\,(N1)^{0.206} + 1n\,(SI)^{0.394} \\ &+ 1n\,(B1)^{1.323} - 4.5986 \\ &* (1 / A1)]\})\ . \end{aligned} \tag{15}$$

Stand growth and yield models can be applied to various basal areas, SIs, initial stand densities, and ages. For example, at SI = 28, stand volume ranged from 4 m^3 per ha at age 6 years and an initial density of 1,100 trees per ha to 319 m^3 per ha at age 50 with an initial density of 18,000 trees per ha at age 6 years (table 3, fig. 5). For SI = 24 at age-6 densities of 1,100 and 18,000 trees per ha, the expected yields are 85 m^3 per ha and 228 m^3 per ha at age 50 years, respectively. At SI = 16, stand volume ranged from 35 m^3 per ha to 99 m^3 per ha (*N* = 1,100 - 18,000) at age 50 years.

Model evaluation—Model (15) provided good estimates at the initial and at future ages. In the case of SSVOB, volumes predicted by model (15) were typically within 5 percent of the observed volumes. Using the actual data from the 35 Ocala National Forest plots to test the model:

$$P\ (SSVOB) = 7.3399 + 0.8767 * A\ (SSVOB)\ ,$$

with R^2 = 0.9421.

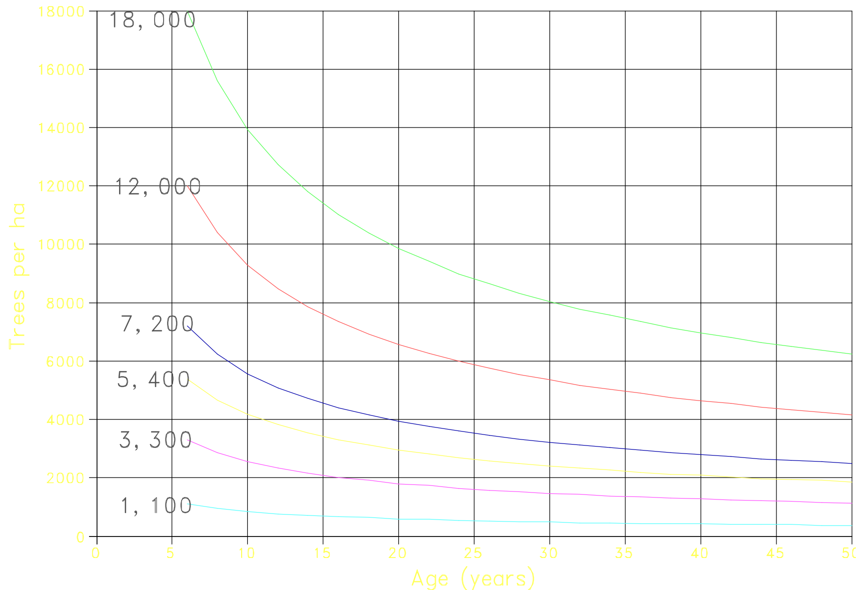


Figure 3—Survival of Ocala sand pine through age 50 years for initial age-6 stand densities ranging from 1,100 to 18,000 trees per hectare.

Table 3—Predicted Ocala sand pine stand total stem volumes outside bark (m^3/ha) at six ages for four site indices and four initial stand densities at age 6 years

Site index	Age	Stand densities 1,100	7,200	12,000	18,000
SI = 16	6	2.5	13.5	22.0	32.6
	10	5.1	16.5	24.2	33.4
	20	15.5	34.2	44.0	54.5
	30	24.0	49.5	61.5	73.9
	40	30.2	60.6	74.4	88.3
	50	34.7	68.9	84.1	99.0
SI = 20	6	2.9	14.2	22.9	33.6
	10	7.4	20.8	29.4	39.4
	20	24.7	51.7	64.7	78.3
	30	38.8	77.4	94.8	112.1
	40	48.9	96.2	116.7	136.8
	50	56.5	110.1	133.0	155.2
SI = 24	6	3.3	15.2	24.0	34.8
	10	10.4	26.5	36.1	47.1
	20	36.6	74.3	91.6	109.2
	30	57.9	113.7	137.9	161.6
	40	73.2	142.2	171.5	199.8
	50	84.6	163.4	196.5	228.1
SI = 28	6	3.9	16.3	25.3	36.4
	10	14.1	33.6	44.5	56.8
	20	51.6	102.6	125.3	147.8
	30	81.8	159.0	191.8	223.5
	40	103.6	199.8	240.1	278.4
	50	119.8	230.1	275.9	319.2

In the 22 plantation plots, the predicted and actual values did not differ significantly and were randomly distributed (fig. 6).

Application

Model (15) may be used to predict future yields when SI and present stand density and age are known. For example, if initial stand density = 5,400 trees per ha at age 12 years and SI = 28, after 6 years (A2 = 18), SSVOB can be derived by (a) estimating future stand density, (b) calculating current and future stand basal area, and (c) converting these estimates to stand volume:

a) $$N2 = 5{,}400 * \exp\left[1.6817 - \ln(18/10)^{0.5005} + \ln(5{,}400)^{0.7954}\right] / \exp\left[1.6817 - \ln(12/10)^{0.5005} + \ln(5{,}400)^{0.7954}\right]$$

$$= 4{,}408 \text{ trees per ha,}$$

b) $$B1 = \exp\left\{-0.03007 + \ln(28)^{1.3915} + \ln\left[5{,}400^{0.7487} - 16.949 * (1/12) - \ln(5{,}400 * 1/12)^{0.3357}\right]\right\} / 100$$

$$= 19.6 \text{ m}^2 \text{ per ha,}$$

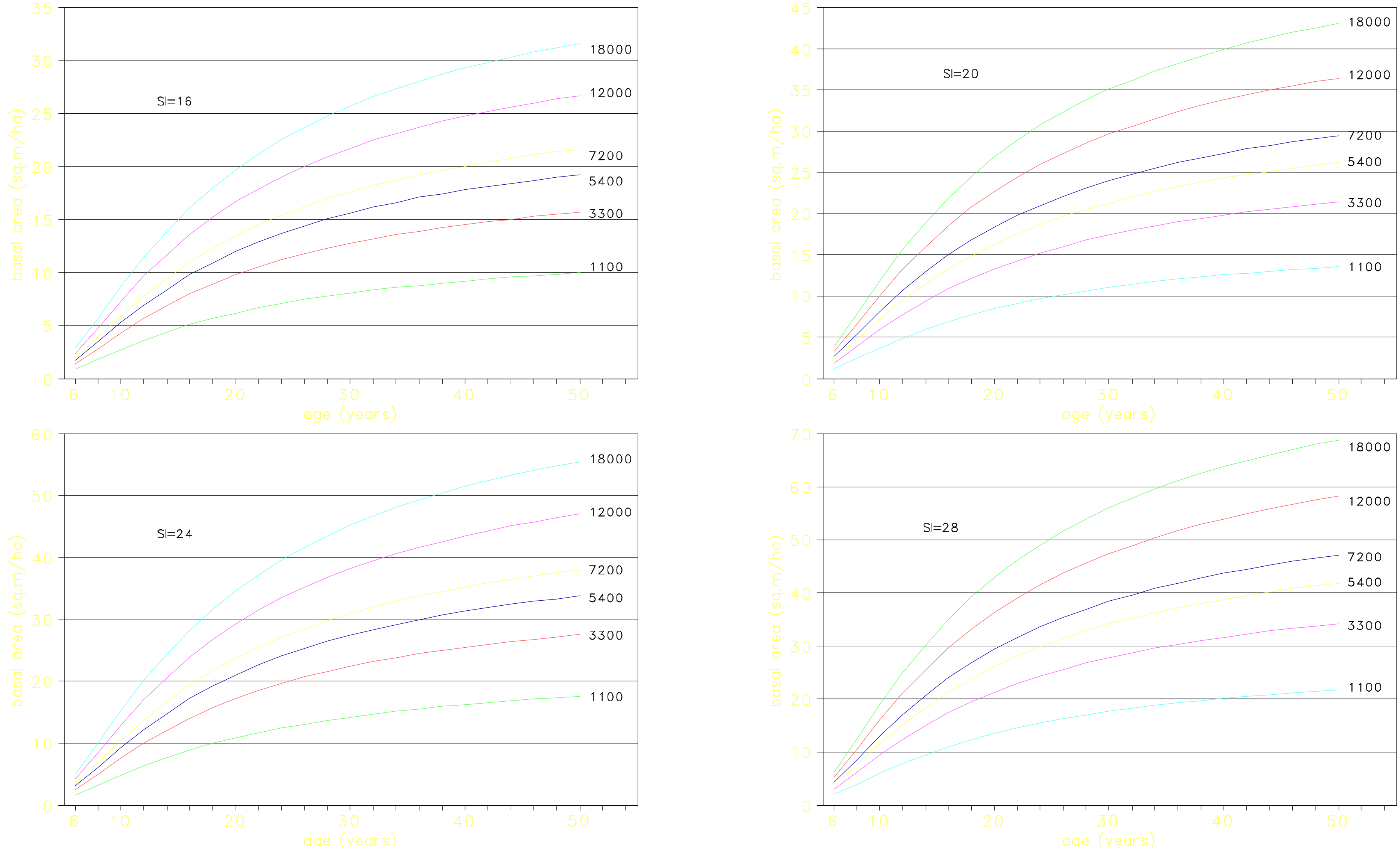


Figure 4—Stand basal area curves for Ocala sand pine at age-6 stand densities of 1 100, 3 300, 5 400, 7 200, 12 000, and 18 000 trees per hectare and site indices of 16, 20, 24, and 28 meters.

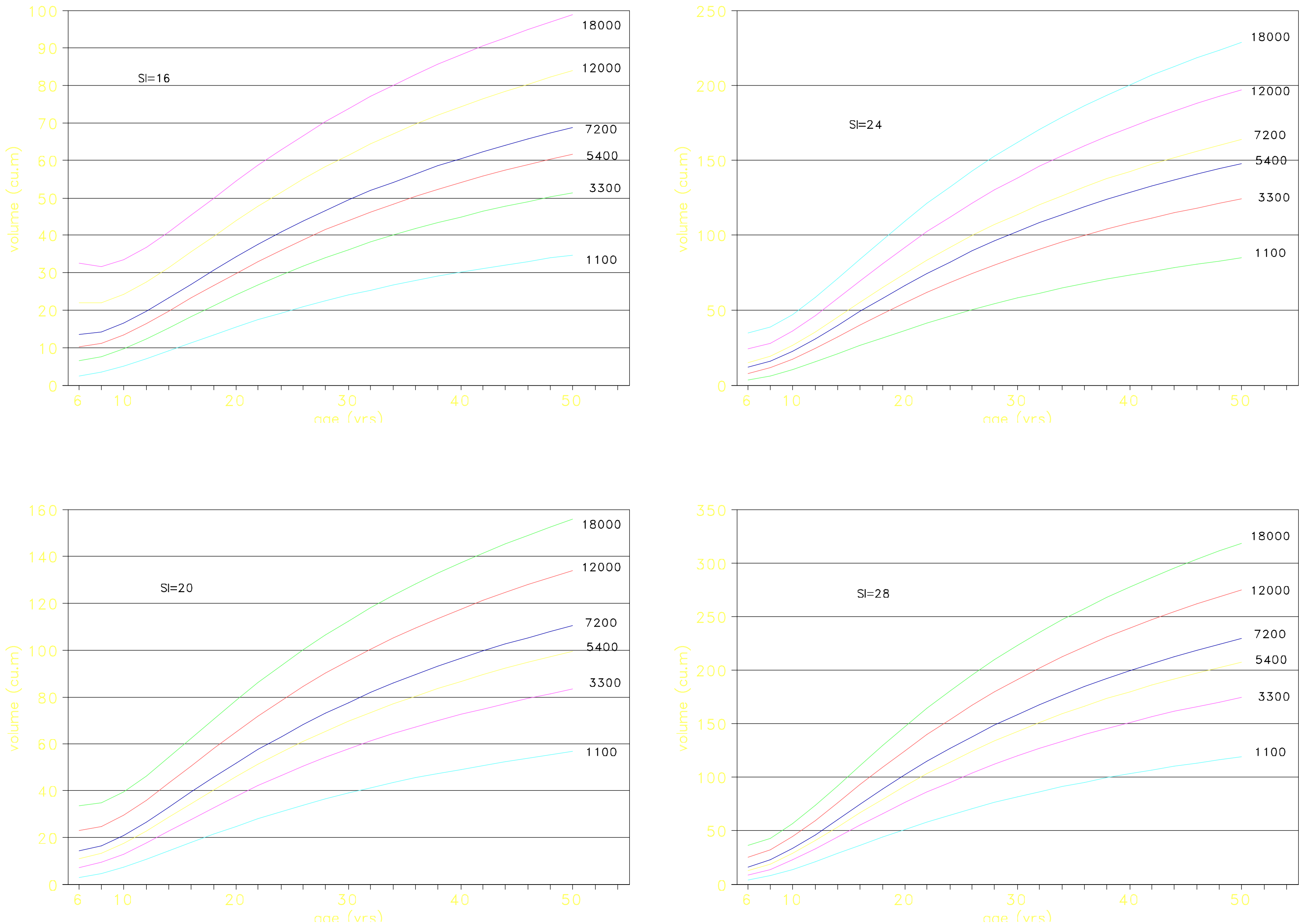


Figure 5—Predicted stand volumes outside bark for Ocala sand pine by site index and age-6 stand densities.

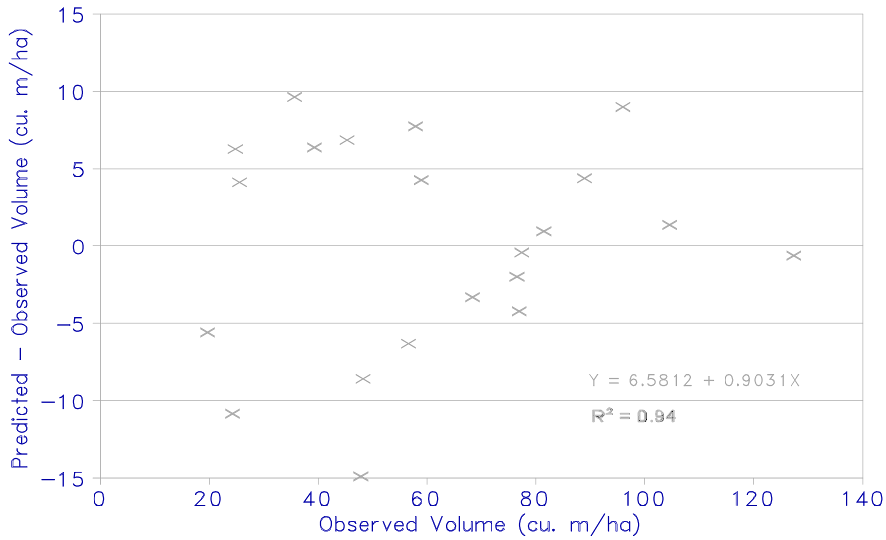


Figure 6—(Predicted-observed) versus observed volumes in Ocala sand pine plantation plots.

$$B2 = B1 * \exp\left[4.5785 + \ln(28)^{1.3957} + \ln(4{,}408)^{0.7487} - 16.949 * (1/18) - \ln(4{,}408 * 1/18)^{0.3357}\right] / \exp\left[4.5785 + \ln(28)^{1.3945} + \ln(5{,}400)^{0.7487} - 16.949 * (1/12) - \ln(5{,}400 * 1/12)^{0.3357}\right]$$

$= 31.0$ m^2 per ha, and

c) $$SSVOB2 = \exp\left(-13.8155 + \ln\left\{1.728 * 10^3 * 4{,}408 + \exp\left[14.5251 - \ln(4{,}408)^{0.206} + \ln(28)^{0.394} + \ln(31.0)^{1.323} - 4.5986 * (1/18)\right]\right\}\right)$$

$= 105.2$ m^3 per ha.

For different management objectives, the best stand option can be selected based on these yield predictions.

Equation (6) can be used to predict stand contents for all traits that can be predicted on an individual tree basis, i.e., the 20 volumes and weights in table 2. By combining volumes and weights with energy values (Rockwood and others 1980), stand energy components can be estimated. These estimates reflect stand yields possible with the seed sources used for direct seeding or nursery propagation until the late 1970’s; improved seed could result in different patterns of stand development (Rockwood and Goddard 1980).

The equations in table 2 have been incorporated into a computer spreadsheet to facilitate yield projections. By specifying initial stand condition and future ages, current and future growth and yield may be readily calculated (table 4). Table 5 displays in English format, current and projected yields for a range of SIs and initial densities. D.L. Rockwood (senior author) will provide a QUATTRO, LOTUS, or EXCEL version of the spreadsheet for yields in metric format, and K.W. Outcalt, the third author, will provide a LOTUS or EXCEL version in English format.

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Table 4—Representative output from the growth and yield spreadsheet for managed Ocala sand pine

				Volume		Weight of																	
		Trees	Basal	whole stem		Stem wood		Stem bark		Whole stem		Branch wood		Branch bark		Branch		Foliage		Crown		Tree	
SI(50)	Age	per ha	area	OB	IB	Green	Dry	Green	Dry	Green	Dry	Green	Dry	OB	IB	Green	Dry	Green	Dry	Green	Dry	Green	Dry
			m^2	- - - - - m^3 - - - -		- *Metric tons* -																	
28	12	5400	19.6	54.4	48.3	46.5	21.2	8.0	4.3	54.5	25.5	24.3	10.6	7.8	3.1	32.1	13.6	19.3	7.5	51.3	21.1	105.8	46.7
28	14	4999	23.9	71.4	65.2	61.6	28.2	9.6	5.2	71.2	33.5	29.5	13.0	9.1	3.5	38.5	16.4	20.4	7.9	58.9	24.4	130.1	57.9
28	16	4676	27.7	88.5	82.2	77.0	35.4	11.2	6.1	88.2	41.5	34.8	15.5	10.5	3.9	45.2	19.3	21.8	8.5	67.0	27.8	155.2	69.3
28	18	4408	31.0	105.2	99.0	92.1	42.4	12.8	7.1	104.9	49.5	40.1	17.9	11.8	4.3	51.9	22.1	23.3	9.0	75.1	31.2	180.0	80.7
28	20	4182	33.9	121.2	115.0	106.6	49.1	14.4	7.9	120.9	57.1	45.2	20.3	13.1	4.7	58.3	24.9	24.7	9.6	82.9	34.5	203.9	91.6
28	22	3987	36.5	136.4	130.3	120.4	55.5	15.9	8.8	136.2	64.3	50.1	22.5	14.4	5.1	64.5	27.5	26.2	10.1	90.5	37.7	226.7	102.0
28	24	3817	38.7	150.7	144.7	133.4	61.6	17.3	9.6	150.6	71.2	54.7	24.6	15.6	5.5	70.3	30.0	27.5	10.6	97.6	40.7	248.3	111.9
28	26	3667	40.8	164.2	158.3	145.7	67.3	18.6	10.3	164.2	77.6	59.1	26.6	16.7	5.9	75.8	32.4	28.8	11.1	104.4	43.6	268.6	121.1
28	28	3534	42.6	176.7	171.0	157.1	72.6	19.9	11.0	176.9	83.6	63.2	28.5	17.8	6.2	80.9	34.6	30.1	11.6	110.8	46.2	287.7	129.8
28	30	3414	44.2	188.5	182.9	167.9	77.6	21.1	11.7	188.8	89.3	67.0	30.3	18.8	6.5	85.8	36.7	31.2	12.0	116.7	48.8	35.6	138.0
28	32	3305	45.7	199.5	194.0	178.0	82.3	22.2	12.3	200.0	94.6	70.6	31.9	19.7	6.8	90.3	38.6	32.3	12.4	122.4	51.1	322.4	145.7
28	34	3206	47.0	209.9	204.5	187.5	86.7	23.2	12.9	210.5	99.5	74.0	33.5	20.6	7.1	94.6	40.5	33.4	12.8	127.6	53.4	338.2	152.9
28	36	3116	48.3	219.6	214.3	196.3	90.8	24.2	13.4	220.4	104.2	77.2	35.0	21.4	7.4	98.6	42.2	34.4	13.2	132.6	55.4	353.0	159.6
28	38	3033	49.4	228.7	223.6	204.7	94.7	25.1	13.9	229.6	108.6	80.2	36.3	22.2	7.6	102.4	43.8	35.3	13.6	137.3	57.4	366.9	166.0
28	40	2956	50.4	237.3	232.3	212.6	98.3	26.0	14.4	238.4	112.7	83.0	37.6	22.9	7.9	105.9	45.3	36.1	13.9	141.7	59.3	380.0	172.0
28	42	2885	51.3	245.3	240.5	220.0	101.8	26.8	14.9	246.6	116.6	85.7	38.9	23.6	8.1	109.3	46.7	37.0	14.2	145.8	61.0	392.4	177.6
28	44	2818	52.2	252.9	248.2	227.0	105.0	27.5	15.3	254.4	120.3	88.2	40.0	24.3	8.3	112.4	48.1	37.7	14.5	149.7	62.7	404.1	183.0
28	46	2756	53.0	260.1	255.6	233.6	108.1	28.3	15.7	261.7	123.8	90.5	41.1	24.9	8.5	115.4	49.4	38.5	14.8	153.5	64.2	415.1	188.0
28	48	2696	53.7	266.9	262.5	239.9	111.0	29.0	16.1	268.6	127.1	92.8	42.1	25.5	8.7	118.2	50.6	39.2	15.0	157.0	65.7	425.6	192.8
28	50	2644	54.4	273.4	269.1	245.8	113.8	29.6	16.5	275.2	130.2	94.9	43.1	26.0	8.9	120.9	51.7	39.8	15.3	160.3	67.1	435.5	197.3
28	52	2592	55.0	279.5	275.3	251.5	116.4	30.2	16.8	281.5	133.2	96.9	44.0	26.5	9.0	123.4	52.8	40.5	15.5	163.4	68.4	444.9	201.6
28	54	2544	55.6	285.3	281.2	256.8	118.9	30.8	17.2	287.4	136.0	98.9	44.9	27.0	9.2	125.9	53.9	41.1	15.8	166.4	69.7	453.8	205.7
28	56	2498	56.1	290.8	286.9	261.9	121.3	31.4	17.5	293.1	138.7	100.7	45.8	27.5	9.3	128.2	54.9	41.6	16.0	169.3	70.9	462.4	209.5
28	58	2454	56.6	296.1	292.3	266.8	123.5	31.9	17.8	298.5	141.3	102.4	46.6	28.0	9.5	130.4	55.8	42.2	16.2	172.0	72.1	470.5	213.2

OB = outside bark; IB = inside bark.

Table 5a—Stem volume and weight for managed Ocala sand pine stands by site index 50, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - -*Ft³*- - - -		- - - - - -*Lb*- - - - - -	
12	405	18	118	101	7,292	3,413
16	350	26	187	169	11,501	5,410
20	313	31	254	234	15,606	7,357
24	286	36	314	294	19,333	9,124
28	265	40	368	347	22,634	10,689
32	248	42	414	393	25,540	12,066
36	234	45	455	434	28,100	13,280
40	222	47	492	470	30,364	14,353
44	211	48	524	502	32,377	15,307
48	202	50	552	531	34,175	16,159
12	607	22	144	120	8,982	4,193
16	526	30	222	198	13,734	6,450
20	470	37	298	273	18,392	8,661
24	429	43	367	341	22,629	10,671
28	397	47	428	401	26,388	12,453
32	372	50	481	454	29,699	14,024
36	350	53	528	501	32,618	15,407
40	332	55	569	543	35,199	16,631
44	317	57	606	579	37,494	17,720
48	303	59	639	612	39,546	18,692
12	809	24	167	137	10,506	4,295
16	701	34	252	222	15,667	7,349
20	627	42	335	305	20,750	9,762
24	572	48	411	380	25,384	11,961
28	530	53	477	446	29,499	13,914
32	495	57	536	504	33,126	15,634
36	467	60	587	556	36,324	17,151
40	443	62	632	601	39,154	18,493
44	422	65	673	642	41,670	19,687
48	404	66	708	678	43,920	20,754
12	1,012	27	189	153	11,928	5,550
16	876	38	280	244	17,418	8,161
20	783	46	368	332	22,849	10,741
24	715	53	449	413	27,809	13,096
28	662	58	520	484	32,218	15,189
32	619	62	583	547	36,107	17,034
36	584	65	638	602	39,537	18,661
40	554	68	687	651	42,573	20,102
44	528	71	730	695	45,273	21,383
48	506	73	769	734	47,688	22,528

OB = outside bark; IB = inside bark.

Table 5b—Stem volume and weight for managed Ocala sand pine stands by site index 55, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - -*Ft³*- - - -		- - - - - -*Lb*- - - - - -	
12	404	21	139	121	8,619	4,041
16	350	29	226	206	13,891	6,542
20	313	36	309	288	19,017	8,971
24	285	41	384	362	23,663	11,174
28	264	45	451	428	27,776	13,123
32	247	48	509	485	31,395	14,838
36	233	51	560	536	34,583	16,349
40	221	53	605	581	37,400	17,684
44	211	55	644	621	39,905	18,871
48	202	57	680	657	42,143	19,932
12	600	25	168	144	10,455	4,891
16	520	35	266	240	16,410	7,718
20	465	42	360	333	22,223	10,475
24	424	48	446	418	27,501	12,978
28	393	53	521	493	32,178	15,195
32	367	57	587	559	36,296	17,147
36	346	60	645	617	39,923	18,867
40	329	63	696	668	43,131	20,387
44	313	65	742	713	45,982	21,739
48	300	67	782	754	48,531	22,947
12	800	28	194	163	12,122	5,662
16	693	39	301	269	18,612	8,744
20	620	48	404	371	24,969	11,760
24	566	54	498	464	30,751	14,503
28	524	60	580	547	35,879	16,935
32	490	64	653	619	40,395	19,077
36	462	68	716	683	44,376	20,964
40	438	71	773	739	47,896	22,633
44	418	73	822	789	24,117	18,258
48	400	75	867	834	53,824	25,444
12	1,000	30	217	180	13,665	6,373
16	866	43	332	294	20,589	9,663
20	774	52	442	404	27,395	12,894
24	707	60	543	504	33,594	15,836
28	654	66	631	593	39,096	18,446
32	612	70	709	671	43,945	20,746
36	577	74	778	740	48,219	22,773
40	547	78	838	800	52,001	24,566
44	522	80	892	854	55,363	26,161
48	500	83	940	903	58,369	27,587

OB = outside bark; IB = inside bark.

Table 5c—Stem volume and weight for managed Ocala sand pine stands by site index 60, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft*^{2}	*Ft*^{3}		*Lb*	
12	400	23	163	144	10,069	4,728
16	346	33	269	248	16,516	7,785
20	310	40	370	347	22,769	10,748
24	283	46	461	437	28,431	13,431
28	262	51	542	517	33,440	15,805
32	245	54	612	587	37,847	17,893
36	231	57	674	649	41,726	19,732
40	219	60	729	703	45,156	21,357
44	209	62	777	752	48,204	22,801
48	200	64	820	795	50,927	24,091
12	600	28	196	171	12,168	5,702
16	520	39	316	289	19,491	9,177
20	465	48	432	403	26,617	12,556
24	424	55	536	506	33,079	15,619
28	393	60	628	597	38,801	18,331
32	367	64	708	678	43,837	20,718
36	346	68	779	748	48,271	22,820
40	329	71	841	811	52,193	24,678
44	313	73	897	866	55,677	26,330
48	300	76	946	916	58,792	27,806
12	800	31	225	193	14,012	6,556
16	693	44	356	322	22,011	10,353
20	620	54	483	448	29,816	14,055
24	566	61	597	561	36,904	17,416
28	524	68	698	662	43,184	20,394
32	490	73	786	750	48,713	23,015
36	462	77	864	828	53,584	25,324
40	438	80	933	897	57,891	27,366
44	418	83	993	958	61,720	29,181
48	400	85	1,048	1,013	65,142	30,804
12	1,000	34	251	213	15,704	7,338
16	866	48	391	352	24,256	11,399
20	774	59	527	487	32,625	15,370
24	707	67	650	609	40,233	18,979
28	654	74	758	717	46,979	22,178
32	612	79	853	813	52,920	24,996
36	577	84	937	897	58,155	27,478
40	547	88	1,011	971	62,786	29,673
44	522	91	1,076	1,037	66,902	31,625
48	500	93	1,135	1,095	70,581	33,370

OB = outside bark; IB = inside bark.

Table 5d—Stem volume and weight for managed Ocala sand pine stands by site index 65, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft*^{2}	*Ft*^{3}		*Lb*	
12	400	26	191	170	11,729	5,513
16	346	37	317	295	19,502	9,198
20	310	45	439	414	27,028	12,765
24	283	52	549	523	33,837	15,991
28	262	57	645	618	39,860	18,845
32	245	61	729	703	45,156	21,354
36	231	64	804	777	49,818	23,563
40	219	67	869	842	53,939	25,516
44	209	69	927	900	57,600	27,250
48	200	71	979	952	60,872	28,801
12	600	31	228	201	14,074	6,604
16	520	44	372	343	22,921	10,800
20	465	53	511	480	31,509	14,871
24	424	61	636	604	39,289	18,559
28	393	67	746	714	46,174	21,822
32	367	72	843	810	52,231	24,693
36	346	76	928	895	57,564	27,220
40	329	79	1,003	970	62,279	29,455
44	313	82	1,069	1,037	66,469	31,440
48	300	85	1,128	1,096	70,214	33,215
12	800	35	259	226	16,115	7,551
16	693	49	418	382	25,793	12,144
20	620	60	570	533	35,211	16,610
24	566	69	707	670	43,753	20,659
28	524	76	828	790	51,316	24,245
32	490	81	935	897	57,972	27,400
36	462	86	1,028	990	63,834	30,178
40	438	89	1,110	1,073	69,017	32,635
44	418	92	1,183	1,146	73,624	34,818
48	400	95	1,249	1,212	77,740	36,769
12	1,000	38	288	248	17,973	8,412
16	866	54	458	416	28,338	13,332
20	774	66	621	579	38,447	18,127
24	707	75	769	726	47,623	22,478
28	654	83	899	856	55,754	26,333
32	612	89	1,013	970	62,910	29,726
36	577	94	1,114	1,071	69,215	32,715
40	547	98	1,202	1,160	74,790	35,358
44	522	101	1,281	1,240	79,746	37,707
48	500	104	1,351	1,310	84,175	39,807

OB = outside bark; IB = inside bark.

Table 5e—Stem volume and weight for managed Ocala sand pine stands by site index 70, age, and density

Age	Density	Basal area	Stem volume OB	Stem volume IB	Stem weight Green	Stem weight Dry
	Trees/ac	*Ft²*	- - - -*Ft³* - - - -		- - - - - -*Lb*- - - - - -	
12	400	29	221	199	13,565	6,382
16	346	41	371	347	22,804	10,762
20	310	50	515	489	31,737	14,995
24	283	57	645	617	39,816	18,822
28	262	63	759	730	46,958	22,206
32	245	68	859	830	53,238	25,181
36	231	71	947	918	58,765	27,800
40	219	74	1,024	995	63,651	30,115
44	209	77	1,093	1,064	67,991	32,171
48	200	79	1,154	1,126	71,870	34,009
12	600	34	262	234	16,182	7,602
16	520	48	434	402	12,596	10,317
20	465	59	598	565	36,918	17,433
24	424	68	746	712	46,155	21,810
28	393	74	877	842	54,327	25,683
32	367	80	991	957	61,514	29,088
36	346	84	1,092	1,057	67,841	32,087
40	329	88	1,180	1,146	73,434	34,737
44	313	91	1,259	1,225	78,404	37,092
48	300	94	1,329	1,296	82,845	39,196
12	800	39	298	262	18,440	8,652
16	693	54	485	448	29,976	14,124
20	620	67	666	627	41,178	19,435
24	566	76	829	789	51,326	24,245
28	524	84	973	932	60,309	28,503
32	490	90	1,098	1,058	68,211	32,248
36	462	95	1,209	1,169	75,169	35,546
40	438	99	1,306	1,267	81,320	38,461
44	418	103	1,393	1,354	86,787	41,052
48	400	106	1,470	1,432	91,672	43,367
12	1,000	42	329	288	20,482	9,600
16	866	60	531	487	32,851	15,469
20	774	73	725	680	44,884	21,175
24	707	84	900	855	55,795	26,348
28	654	92	1,055	1,009	65,457	30,928
32	612	99	1,190	1,145	73,958	34,958
36	577	104	1,309	1,265	81,445	38,507
40	547	109	1,414	1,370	88,065	41,645
44	522	112	1,507	1,464	93,949	44,434
48	500	116	1,590	1,548	99,207	46,926

OB = outside bark; IB = inside bark.

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Sand pine is a very important species in Florida, producing significant quantities of fiber. The purpose of this study was to develop the site index and stand-level growth and yield equations managers need to make informed decisions. Data were collected from 35 seeded plots of Ocala sand pine covering a range of site indexes, ages, and densities in 1982-83. These plots were remeasured 5 and 10 years later and the data used to develop growth and yield equations by tree component. Equations for both current and future yields in volume and weight measures are given. These equations gave very good results when tested by comparing actual yields with predicted yields for a second set of 22 sand pine plantations measured in the panhandle area of Florida.

Keywords: Biomass, growth, site index, survival, yield.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.